

What is claimed is:

1. A system for manufacturing three-zone microporous membrane, the system comprising:
  - 5 at least one vessel for containing a ternary phase inversion polymer mother dope, the dope having been exposed to a mixing temperature which is sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the dope contained therein being maintained at a temperature sufficient to stabilize and maintain the mixture after completion of the mixing;
  - 10 a dope processing site;
  - 15 at least one pressure means, operatively connected to the at least one vessel, and the dope processing site for moving the dope from the at least one vessel to the dope processing site;
  - 20 a dope transportation system, operatively connected to the at least one vessel and the dope processing site, for transfer of the dope from the vessel to the dope processing site;
2. The system of claim 1 further comprising:
  - 5 at least one thermal manipulation means, operatively connected to the at least one vessel and the dope processing site, for transforming the dope into any one of a plurality of different possible pore size producing dopes; and
  - 10 at least one dope application means, operative at the dope processing site and operatively connected to the at least one thermal manipulation means, for applying the dope at the dope processing site.
3. The system of claim 2 further comprising:
  - 5 at least a second thermal manipulation means, operatively connected to the at least one vessel, the dope transportation system and the at least a second dope application means, for transforming the dope into any one of a plurality of different possible pore size producing dopes for application at the dope processing site by the at least a second dope application means.
  - 10 at least a third thermal manipulation means, operatively connected to at least one vessel, the dope transporting system and the at least a

third dope application means, for transforming the dope into any one of a plurality of different possible pore size producing dopes for application at the dope processing site by the at least a third dope application means.

4. The system of claim 1 further comprising:

at least a second and a third dope application means operative at the dope processing site; and

at least a second and a third thermal manipulation means,

5 operatively connected to the at least one vessel and the at least second and third dope application means respectively, for transforming the dope pumped from the at least one vessel to the second and the third thermal manipulation means into any one of a plurality of different possible pore size producing dopes for application at the dope processing site.

5. The system of claim 1 further comprising:

at least a second vessel operatively connected to the dope transporting means, for containing a ternary phase inversion polymer dope, the dope having been exposed to a mixing temperature sufficient to effect

5 dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the vessel and the dope contained therein being maintained at a temperature sufficient to stabilize and maintain the mixture after cooling from the mixing temperature.

6. The system of claim 5 further comprising:

10 at least a third vessel, operatively connected to the dope transporting system, for containing a ternary phase inversion polymer dope, the dope having been exposed to a mixing temperature sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the vessel and the dope contained therein being maintained at a temperature 15 being sufficient to stabilize and maintain the mixture after cooling from the mixing temperature.

7. The system of claim 1 further comprising:

bypass means, operatively connected to the at least one thermal manipulation means, for diverting dope being transported from the at least one vessel to the dope processing site such that the dope is not processed by the at 5 least one thermal manipulation means prior to delivery to the dope processing site.

8. The system of claim 2 further comprising:

bypass means, operatively connected to the at least the second thermal manipulation means, for diverting dope from at least one vessel to the dope processing site such that the dope is not processed by the at least second thermal manipulation means prior to delivery to the dope processing site.

5 9. The system of claim 3 further comprising:

bypass means, operatively connected to at least the third thermal manipulation means, for diverting dope from the at least one vessel to the dope processing site such that the dope is not processed by the at least 5 third thermal manipulation means prior to being delivered to the processing site.

10. The system of claim 1 wherein the thermal manipulation means further comprises:

heating means, operatively positioned in the at least one thermal manipulation means, for elevating the temperature of at least a portion 5 of the dope to a temperature within about  $\pm 0.2^{\circ}\text{C}$  of a predetermined temperature, the predetermined temperature being selected from a calibrated characterization curve which describes the relationship between the dope being processed and the resulting pore size in at least one zone of the three-zone microporous membrane.

11. The system of claim 10 wherein the thermal manipulation means further comprises:

cooling means, operatively connected to the at least one thermal manipulation means, for cooling the dope after processing by the 5 thermal manipulation means to a temperature such that the dope has a viscosity sufficient for processing by at least one dope application means to produce a microporous phase inversion membrane.

12. The system of claim 10 wherein the heating means further comprises:

first heating means, operatively connected to the pump, for elevating the temperature of at least a portion of the dope to a temperature 5 within about  $2^{\circ}\text{C}$  below the predetermined temperature; and

second heating means, operatively connected to the first heating means, for further elevating the temperature of at least a portion of the dope to a temperature no higher than within about  $\pm 0.2^{\circ}\text{C}$  of the predetermined temperature.

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13. The system of claim 12 wherein the second heating means further elevates the temperature of the dope to a temperature no higher than within about  $\pm 0.15^{\circ}\text{C}$  of the predetermined temperature.

14. The system of claim 1 further comprising:

means, operatively positioned between the vessel containing the ternary phase inversion polymer and the dope processing site, for controlling the thickness of the dope during applied by the application means.

15. The system of claim 1 further comprising:

means, operatively positioned between the vessel containing the ternary phase inversion polymer and the dope processing site, for controlling the coating weight of the dope during application by the application means.

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16. The system of claim 1 wherein the mother dope further comprises:

a phase inversion membrane polymer, a solvent and a nonsolvent in solution.

17. The system of claim 16 wherein the phase inversion membrane polymer is selected from the group consisting of:

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copolymers of hexamethylene diamine and adipic acid (nylon 66), copolymers of hexamethylene diamine and sebacic acid (nylon 610), homopolymers of polycaprolactam (nylon 6) and copolymers of tetramethylenediamine and adipic acid (nylon 46).

18. The system of claim 16 wherein the phase inversion membrane polymer consists of:

copolymers of hexamethylene diamine and adipic acid (nylon 66).

19. The system of claim 16 wherein the phase inversion membrane polymer is selected from the group consisting of:

polyamide resins have a ratio of methylene ( $\text{CH}_2$ ) to amide ( $\text{NHCO}$ ) groups within the range of about 4:1 to about 8:1.

20. The system of claim 16 wherein the phase inversion membrane polymer is selected from the group consisting of:

polyamide resins have a ratio of methylene ( $\text{CH}_2$ ) to amide ( $\text{NHCO}$ ) groups within the range of about 5:1 to about 7:1.

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21. The system of claim 16 wherein the phase inversion membrane polymer has a molecular weight, within the range from about 15,000 to about 42,000 (number average molecular weight).

22. The system of claim 16 wherein the phase inversion membrane polymer is polyhexamethylene adipamide (nylon 66) having molecular weights above about 30,000 (number average molecular weight).

23. The system of claim 1 further comprising:

at least a second dope application means; and

5 at least a second thermal manipulation means, operatively positioned between the at least one vessel and the at least a second dope application means, for transforming the dope pumped from the at least one vessel to at least the second thermal manipulation means into any one of a plurality of different pore size producing dopes for application at the dope processing site by the at least second application means.

24. A system for manufacturing three-zone microporous membrane, the system comprising:

5 at least one vessel for containing a ternary phase inversion polymer mother dope, the dope having been exposed to a mixing temperature sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the vessel and the dope contained therein being maintained at a temperature sufficient to stabilize and maintain the mixture after cooling from the mixing temperature;

10 a dope processing site, operatively connected to the at least one vessel containing the ternary phase inversion polymer mother dope;

a dope transportation system, operatively connected to the at least one vessel and to the dope processing site, for transporting the dope from the vessel to the dope processing site;

15 means, operatively connected to the at least one vessel, for moving the dope from the at least one vessel to the dope processing site;

at least three thermal manipulation means, operatively connected to the at least one vessel, the dope transportation system and the dope processing site, for transforming the dope into any one of a plurality of different possible pore size producing dopes; and

20 at least three dope application means, each operatively connected to a respective one of the three thermal manipulation means for application of the dope delivered to the dope processing site.

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25. A method for manufacturing a three-zone microporous membrane, the method comprising the steps of:

providing at least one vessel for containing a ternary phase inversion polymer mother dope;

5 formulating a ternary phase inversion polymer mother dope in the at least one vessel to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent;

10 maintaining the mother dope in the vessel at a temperature sufficient to stabilize and maintain the dope formulated after cooling from the formulation temperature;

10 providing a dope processing site having at least one dope application means;

15 operatively connecting the at least one vessel to the dope processing site such that the mother dope is transported from the at least one vessel to the dope processing site;

15 operatively positioning at least one thermal manipulation means between the at least one vessel and the dope processing site;

20 thermally manipulating the mother dope transported from the at least one vessel in the at least one thermal manipulation means into any one of a plurality of different possible pore size producing dopes; and

20 applying a predetermined one of the plurality of different possible pore size producing dopes received from the at least one thermal manipulation means to a scrim at the dope processing site to produce reinforced, three-zone microporous membrane.

26. The method of claim 25 further comprising the steps of:

operatively positioning at least a second dope application means at the dope processing site;

5 operatively positioning at least a second thermal manipulation means between the at least one vessel and the at least a second dope application means;

10 thermally manipulating the mother dope transported from the at least one vessel in the at least second thermal manipulation means into a predetermined one of a plurality of different possible pore size producing dopes; and

10 applying the predetermined one of the plurality of different possible pore size producing dopes received from each of the two thermal

15 manipulation means to a scrim that has had a thermally manipulated dope applied thereto from one of the at least two thermal manipulation means to produce reinforced, three-zone microporous membrane.

27. The method of claim 26 further comprising the steps of:  
operatively positioning at least a third dope application means at the dope processing site;

5 operatively positioning at least a third thermal manipulation means between the at least one vessel and the at least third dope application means;

10 thermally manipulating the mother dope transported from the at least one vessel in at least the third thermal manipulation means into a predetermined one of a plurality of different possible pore size producing dopes; and

applying the predetermined one of the plurality of different possible pore size producing dopes received from each of the three thermal manipulation means to a scrim at the dope processing site to produce reinforced, three-zone microporous membrane.

28. The method of claim 27 further comprising the steps of:  
5 providing at least a second vessel for containing a ternary phase inversion polymer mother dope, the dope having been exposed to a mixing temperature sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the vessel and the dope contained therein being maintained at a temperature sufficient to stabilize and maintain the mixture after cooling from the mixing temperature.

29. The method of claim 27 further comprising the steps of:  
5 providing at least a third vessel for containing a ternary phase inversion polymer mother dope, the dope having been exposed to a mixing temperature sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the vessel and the dope contained therein being maintained at a temperature sufficient to stabilize and maintain the mixture after cooling from the mixing temperature.

30. The method of claim 28 wherein during the thermal manipulation step, the temperature of the mother dope is incrementally elevated to a temperature no higher than within about  $\pm 0.15^{\circ}\text{C}$  of the predetermined temperature.

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31. A system for manufacturing three-zone microporous membrane, the system comprising:

5 at least one vessel for containing a ternary phase inversion polymer mother dope, the dope having been exposed to a mixing temperature which is sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the dope contained therein being maintained at a temperature sufficient to stabilize and maintain the mixture after completion of the mixing;

10 a dope processing site; means, operatively connected to the at least one vessel, for moving the dope from the at least one vessel to the dope processing site;

a dope transportation system, operatively connected to the at least one vessel and the dope processing site, for transfer of dope from the vessel to the dope processing site;

15 at least one thermal manipulation mechanism, operatively connected to the at least one vessel and the dope processing site, for transforming the dope into any one of a plurality of different possible pore size producing dopes; and

20 at least one dope application mechanism operative at the dope processing site and operatively connected to the at least one thermal manipulation mechanism, for applying the thermally manipulated dope at the dope processing site.

32. The system of claim 31 further comprising:

at least a second dope application mechanism operative at the dope processing site; and

5 at least a second thermal manipulation mechanism, operatively connected to the at least one vessel, the dope transportation system and the at least a second dope application mechanism, for transforming the dope into any one of a plurality of different possible pore size producing dopes for application at the dope processing site by the at least second dope application mechanism.

33. The system of claim 32 further comprising:

at least a third dope application mechanism operative at the dope processing site; and

5 at least a third thermal manipulation mechanism, operatively connected to at least one vessel, the dope transporting system and the at least a

second dope application mechanism, for transforming the dope into any one of a plurality of different possible pore size producing dopes for application at the dope processing site by the at least third application mechanism.

34. The system of claim 31 further comprising:

at least a second and a third dope application mechanism operative at the dope processing site; and

at least a second and a third thermal manipulation mechanism,

5 operatively connected to the at least one vessel and at least the second and the third dope application mechanisms respectively, for transforming the dope pumped from the at least one vessel to the second and the third thermal manipulation mechanism into any one of a plurality of different possible pore size producing dopes for application at the dope processing site.

35. The system of claim 31 further comprising:

at least a second vessel operatively connected to the dope transporting mechanism, for containing a ternary phase inversion polymer dope, the dope having been exposed to a mixing temperature sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the vessel and the dope contained therein being maintained at a temperature sufficient to stabilize and maintain the mixture after cooling from the mixing temperature.

36. The system of claim 35 further comprising:

at least a third vessel, operatively connected to the dope transporting system, for containing a ternary phase inversion polymer dope, the dope having been exposed to a mixing temperature sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the vessel and the dope contained therein being maintained at a temperature being sufficient to stabilize and maintain the mixture after cooling from the mixing temperature.

37. The system of claim 31 further comprising:

5 a bypass mechanism, operatively connected to the at least one thermal manipulation mechanism, for diverting dope being transported from the at least one vessel to the dope processing site such that the dope is not processed by the at least one thermal manipulation mechanism prior to delivery to the dope processing site.

38. The system of claim 32 further comprising:

5 a bypass mechanism, operatively connected to the at least the second thermal manipulation mechanism, for diverting dope from at least one vessel to the dope processing site such that the dope is not processed by the at least second thermal manipulation mechanism prior to delivery to the dope processing site.

39. The system of claim 33 further comprising:

5 a bypass mechanism, operatively connected to at least the third thermal manipulation mechanism, for diverting dope from the at least one vessel to the dope processing site such that the dope is not processed by the at least third thermal manipulation mechanism prior to being delivered to the processing site.

40. The system of claim 31 wherein the thermal manipulation mechanism further comprises:

5 at least one heating mechanism, operatively positioned in the at least one thermal manipulation mechanism, for elevating the temperature of at least a portion of the dope to a temperature within about  $\pm 0.2^{\circ}\text{C}$  of a predetermined temperature, the predetermined temperature being selected from a calibrated characterization curve which describes the relationship between the dope being processed and the resulting pore size in at least one zone of the formed three-zone membrane.

41. The system of claim 40 wherein the thermal manipulation mechanism further comprises:

5 at least one cooling mechanism, operatively connected to the at least one thermal manipulation mechanism, for cooling the dope after processing by the thermal manipulation mechanism to a temperature such that the dope has a viscosity sufficient for processing by at least one dope application mechanism to produce a microporous phase inversion membrane.

42. The system of claim 40 wherein the at least one heating mechanism further comprises:

5 a first heating mechanism, operatively connected to the pump, for elevating the temperature of at least a portion of the dope to a temperature within about  $2^{\circ}\text{C}$  below the predetermined temperature; and

a second heating mechanism, operatively connected to the first heating mechanism, for further elevating the temperature of at least a portion of the dope to a temperature no higher than within about  $\pm 0.2^{\circ}\text{C}$  of the predetermined temperature.

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43. The system of claim 42 wherein the second heating mechanism further elevates the temperature of the dope to a temperature no higher than within about  $\pm 0.15^{\circ}\text{C}$  of the predetermined temperature.

44. The system of claim 31 further comprising:  
a mechanism, operatively positioned at the dope processing site, for controlling the thickness of the dope during application by the application mechanism.

45. The system of claim 31 further comprising:  
a mechanism, operatively positioned between the vessel containing the ternary phase inversion polymer and the dope processing site, for controlling the coating weight of the dope during application by the application mechanism.

46. The system of claim 31 wherein the mother dope further comprises:

a phase inversion membrane polymer, a solvent and a nonsolvent in solution.

47. The system of claim 46 wherein the phase inversion membrane polymer is selected from the group consisting of:

5 copolymers of hexamethylene diamine and adipic acid (nylon 66), copolymers of hexamethylene diamine and sebamic acid (nylon 610), homopolymers of polycaprolactam (nylon 6) and copolymers of tetramethylenediamine and adipic acid (nylon 46).

48. The system of claim 46 wherein the phase inversion membrane polymer consists of:

copolymers of hexamethylene diamine and adipic acid (nylon 66).

49. The system of claim 46 wherein the phase inversion membrane polymer is selected from the group consisting of:

polyamide resins have a ratio of methylene ( $\text{CH}_2$ ) to amide ( $\text{NHCO}$ ) groups within the range of about 4:1 to about 8:1.

50. The system of claim 46 wherein the phase inversion membrane polymer is selected from the group consisting of:

polyamide resins have a ratio of methylene ( $\text{CH}_2$ ) to amide ( $\text{NHCO}$ ) groups within the range of about 5:1 to about 7:1.

51. The system of claim 46 wherein the phase inversion membrane polymer has a molecular weight, within the range from about 15,000 to about 42,000 (number average molecular weight).

52. The system of claim 46 wherein the phase inversion membrane polymer is polyhexamethylene adipamide (nylon 66) having molecular weights above about 30,000 (number average molecular weight).

53. A system for manufacturing three-zone microporous membrane, the system comprising:

at least one vessel for containing a ternary phase inversion polymer mother dope, the dope having been exposed to a mixing temperature sufficient to effect dissolution and equilibrium mixing of the polymer, solvent and nonsolvent, the vessel and the dope contained therein being maintained at a temperature sufficient to stabilize and maintain the mixture after cooling from the mixing temperature;

5 10 a dope transportation system, operatively connected to the at least one vessel and to a dope processing site, for transporting the dope from the vessel to the dope processing site;

15 at least one pump, operatively connected to the at least one vessel, for moving the dope from the at least one vessel to the dope processing site;

20 20 at least three thermal manipulation mechanisms, operatively connected to the at least one vessel, the dope transportation system and the dope processing site, for transforming the dope from the at least one vessel into any one of a plurality of different possible pore size producing dopes; and

25 at least three dope application mechanisms, operatively connected to each of the three thermal manipulation mechanisms for application of the dope delivered to the dope processing site.